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(54) Compact image capture device

(57) The image capture device incorporates an array of photodetectors (100), utilizing an integral current mirror formed at each photodetector location to increase photodetector current output. A correlated double sampling circuit is also formed at each photodetector location to sum the current generated by the current mirror over each exposure period, so as to produce a voltage proportional to the radiation intensity incident at each photodetector location. The correlated double sampling circuit is used to reduce noise in the photodetected signal and to eliminate the effect of dark current. Combining the image capture device with a unique lenslet array (210) forms an extremely compact optical array camera. An embodiment with a mechanical shutter is also disclosed.

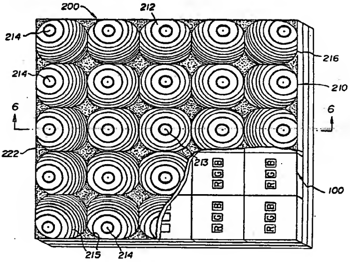

Fig. 5

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Description

Cross-Reference To Related Applications

The present application is related to U.S. Application Serial Number 08/652,735, filed May 23, 1996, by Mark M. Meyers, and entitled, "A Diffractive/Refractive Lenslet Array;" U.S. Application Serial Number 08/417,422, filed April 5, 1995, by Mark M. Meyers, and entitled, "A Blur Filter For Eliminating Aliasing In Electrically Sampled Images;" U. S. Application Serial Number 08/663,887, filed June 14, 1996, by Mark M. Meyers, and entitled, "A Diffractive/Refractive Lenslet Array Incorporating A Second Aspheric Surface;" U.S. application Serial Number 08/684,073, filed July 18, 1996, by Mark M. Meyers, and entitled, "Lens."

FIELD OF THE INVENTION

This invention relates generally to the field of image capture devices and more particularly to an improvement that integrates circuits into the areas between the individual photodetectors forming the image capture device and to their combination for forming an optic array camera.

BACKGROUND OF THE INVENTION

U.S. Patent No. 5,471,515, to Fossum, et. al., entitled "Active Pixel Sensor with Intra-Pixel Charge Transfer." This invention converts the photogenerated charge stored under the photogate into a voltage by transferring the charge to a sense node (typically a capacitor) located within the active pixel unit cell. Fossum then utilizes dual sample correlated double sampling of the voltage based signal to reduce signal noise and eliminate the effect of dark current from the photosensor. The voltage associated with the image exposure is then subtracted from the voltage associated with a read during a dark sample by a voltage differencing amplifier located at the end of the row or column of the photosensors. By using appropriate row and column selection transistors a subsection of the array can be read out without the need to read out the entire image array. The Fossum invention does not however allow for an increase in the overall sensitivity of the CCD detector elements, nor does it envision the utilization of an array optic type structure to form an image of different segments of the field of view, although the patent does disclose the use of a lens array for concentrating light on the active pixel. Fossum does not include means for adjusting the overall exposure level of the pixel internal to the unit cell of the detector array. Fossum is also performing most of the signal processing in a voltage amplification mode, whereas the present invention utilizes the advantages of the current mode of signal processing.

In U.S. Patent No. 5,004,901, entitled "Current Mirror Amplifier for use in an Optical Data Medium Driving Apparatus and Servo Circuit" to Yoshimoto, et. al., photogenerated current from an optical disk tracking and read sensor is amplified in fixed steps by a switchable series of current mirrors, where the current mirrors achieve current multiplication through the use of output stages that incorporate either multiple output transistors with the bases of the output transistors connected in parallel or by the use of output transistors with emitter areas that are integral multiples of the emitter areas of the input side transistor. The purpose of Yoshimoto's invention is to allow the utilization of received photocurrents with a large dynamic range by multiplying the input current by an adjustable ratio, where the multiple current ratios are selected through a switchable network of differential amplifiers. Yoshimoto's invention is not related to the field of array image sensors and requires the use of a switchable array of differencing amplifiers. Yoshimoto's invention does not integrate the current from the photosensor and the current is continuously generated by received light from the laser light emitted by the optical disk head. Therefore, the sensor is not exposed to an image with its sensed signals being integrated by signal processing electronics, as in the current invention, but is rather used in a continuous optical disk position monitoring mode. Yoshimoto does not utilize dual slope correlated double sampling for noise reduction as disclosed in the present invention. Yoshimoto does not make any mention of the use of array optics with a field of view which varies as a function of radial position in the sensor array.

SUMMARY OF THE INVENTION

The present invention is directed to overcoming one or more of the problems set forth above. Briefly summarized, according to one aspect of the present invention there is provided a photosensitive array comprised of a plurality of current generating photodetectors in combination with a plurality of multiplying current mirrors wherein each multiplying current mirror is comprised of one input transistor and two or more output transistors or an output transistor with an emitter area which is N times the area of the input transistor. The photocurrent from each photodetector is multiplied by an integer equal to the number of output transistors in the multiplying current mirror.

From the aforementioned it can be seen that it is a primary object of the present invention to provide an improved photosensor array incorporating integrated support electronics.

It is yet another object of the present invention to provide a short focal length camera based on the improved photosensor array of the present invention.

It is another object of the present invention to provide a compact photosensor array that incorporates support electronics close to the source of generated photocurrent.

These and other aspects, objects, features, and advantages of the present invention will be more clearly understood and appreciated from a review of the following detailed description of the preferred embodiments and appended claims, and by reference to the accompanying drawings.

Advantageous Effect Of The Invention

The present invention has the advantages of increased signal current produced by a combination of current mirrors positioned in close physical proximity to associated arrayed photodetectors where the increased signal current represents an increase in sensitivity for the photosensor array. This increased sensitivity, in turn, allows for the use of shorter exposure times, or the use of optics with smaller numerical apertures when the photosensor array is used in a camera. The use of lower numerical aperture optics (higher F/#'s) in a camera allows for greater depth of focus, easier alignment of optics and photosensor and in general decreased system costs. In the camera implementation of the invention either a mechanical or an electrical shutter may be used.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic diagram of a unit pixel assembly that may be arranged in an array and used in a device such as a camera to capture an image;

Fig. 2 is a circuit diagram of an alternate embodiment of a portion of the unit pixel assembly of Fig. 1;

Fig. 3 is a circuit diagram of another embodiment of a portion of the unit pixel assembly of Fig. 1;

Fig. 4 is a perspective view of an electronic camera incorporating a plurality of unit pixel subassemblies arranged as a photosensor array located at the focal plane of the objective lens;

Fig. 5 is a top view of an optic array camera incorporating a plurality of unit pixel subassemblies;

Fig. 6 is a section view of the photosensor array of Fig. 5 taken along the section lines 6-6; and

Fig. 7 illustrates a camera using a mechanical shutter in combination with the photosensor array of Figs. 5 and 6.

To facilitate understanding, identical reference numerals have been used, where possible, to designate identical elements that are common to the figures.

DETAILED DESCRIPTION OF THE INVENTION

Referring to Fig. 1, a unit pixel subassembly 10, forms part of a camera's photosensor array 100 (see array of Fig. 4). The unit pixel subassembly 10 is comprised of a photodetector 20, which may be, for example, a CCD device and/or a photodiode. The output 22 of the photodetector 20 is connected to a transfer gate 24, a reset gate 26, and a multiplying current mirror 30A. The transfer gate 24 allows the charge, accumulated by the photodetector 20 during the exposure period, to be transferred to the multiplying current mirror 30A at the desired time. When closed the reset gate 26 allows for the emptying of the photodetector's 20 accumulated charge from the previously completed exposure. When the reset gate 26 is opened and the camera's shutter 110 (see Fig. 4) is closed the output from the photodetector 20 is integrated for a time equivalent to the previous exposure time so as to cancel dark current and noise. This cancellation occurs within a correlated double sampling circuit 40. The photosensor array 100 is then ready for exposure to a new image.

As is well known the output of the current mirror 30A is a multiple of the current produced by the photodetector 20. The current multiplying effect is traditionally accomplished either by connecting the bases or gates of the transistors 32_1 through 32_n in parallel with each other or by making the emitter (or source) areas larger by an integral multiple of the emitter area of an input slide transistor 34. Current mirrors of this type operate on the principle that the emitter base voltage (or the gate source voltage) for all the transistors in the current mirror are the same so that each of the collector (drain) currents is the same, and therefore the sum of the currents from the output side T_o is a multiple of either the number of transistors in the output side or the ratio of the area. This current multiplication is represented mathematically as follows as:

$$I_{out} = n * I_{in}$$

where

n = number of transistors on the output side "T_o" of the current mirror

or

$$n = A_{out} / A_{in} = \text{the ratio of emitter areas}$$

with detailed analysis it can be shown that output current is not as simple as the above equation and is more accurately represented by

$$I_{out} = n * (I_{in} / (1+ \beta))$$

where

as a function of the particular lenslet's radial position on the array. Therefore, by appropriately forming the decenters of each lenslet each photosensitive site 217 will view a different segment of a scene (image). Since each photosensor group 222 has its own lenslet there is no need to reinvert the image with a relay lens.

Therefore, any camera system, incorporating the present invention, can be extremely compact and flat due to the integration of the above described circuitry which allows for the elimination of support circuit boards which in turn allows for a further decrease in the size of the camera. The camera can work in black and white or in color if three unit pixel subassemblies with color filters are formed at each pixel site 217 to pass only assigned frequencies of incident radiation. The use of a lenslet that will physically displace incident radiation may be used in lieu of color filters to deflect the appropriate frequency of incident radiation to its assigned photosensor.

An array of aspheric lenslets can also be used to form images on the photosensor array 100. However, the aforementioned embodiment does not correct for the variation in focal length as a function of wavelength since the lenslet is formed from a single refractive material, therefore the spot size of the incident light varies as a function of color.

By utilizing a multiplying current mirror to increase the photocurrent generated at each photosite the effective sensitivity of the photosensor array is increased. Prior art photosensitive arrays (such as CCD arrays) require the use of lenses with very high numerical apertures (low F/#'s, typically on the order of F/1.8 to F/4.0) which are more difficult to align, harder to keep in focus and in general cost more than lower F/# objective lenses. For an array optic camera with a field of view which varies as a function of radial position in the photosensitive array, the use of a photosensor unit cell with increased sensitivity will allow for the use of lower F/# optics. The definition of lens F/# is

$$F/\# = \text{Focal Length/Lens Diameter}$$

Reducing each lenslet's F/# allows for the reduction of the center-to-center spacing between array elements, since, for a given F/# and detector sensitivity a specific photocurrent is generated. The illumination incident on the detector array from a given lenslet is proportional to the $(F/\#)^2$. Therefore, if the sensitivity is increased by x, the F/# can be reduced by $x^{1/2}$. For instance, if an array optic camera, without multiplying current mirror, is used with a lenslet having a F/# = 4.0 and a FL = 0.5 mm the lenslet's diameter would be 250 µm. Therefore, if an array optic camera is formed with 780 by 640 pixels the length of the long dimension of the array would be 32.5 mm, assuming 3 color pixels (photosensors) at each photosite. This would require a large area of silicon per photosensor array, which would increase part costs and result in lower yields of photosensors from a given wafer size. By incorporating a current mirror with a multiplication factor of 16 at each photosite the lenslet diameters can be reduced by 4x to 65 µm and the length of the array will be reduced to 8.125 mm, resulting in higher photosensor yields and lower part costs. The array optic camera can utilize this technique with no decrease in usable photosensitive surface area since the space between photosites is not utilized for light detection, but is rather, empty space.

Fig. 7 illustrates the optic array camera 200 of Fig. 6 positioned in a light tight housing 252 that is exposed to an image via a mechanical shutter 250. The mechanical shutter may be any of the typical shutters used in a film type camera. The advantage to the optic array camera 200 of Fig. 6 is that no mechanical shutter is required; the photosensors 222 are turned "on" or active to capture light from the image focused onto the photosensor array 100. In the Fig. 7 embodiment the photosensors 222 are turned "on" generally when camera power is on and image capture occurs when the shutter 250 is activated.

The invention has been described with reference to a preferred embodiment; However, it will be appreciated that variations and modifications can be effected by a person of ordinary skill in the art without departing from the scope of the invention.

PARTS LIST:

10	unit pixel subassembly
20	photodetector
22	output
24	transfer gate
26	reset gate
30A	multiplying current mirror
30B	current mirror circuit
30C	current mirror
32_1 - 32_n	output side transistors
34	input side transistors
36	transistor
40	correlated double sampling circuit
42	+1 amp
44	-1 amp
46	integrating amplifier
50	data bus
52	column selection transistors
54	row selection transistors
100	photosensor array
110	shutter
120	camera
200	optic array camera
210	lenslet array
212	achromatized refractive/diffractive lenslet
213	optical axis (central)
214	optical axis (central)
215	lines
216	opaque mask
217	photosensitive sites

218	light spacers and/or baffles
222	photosensors
240	field stop aperture plate
250	mechanical shutter
252	light tight housing
T_o	output transistor
T_I	input transistor

Claims

1. A compact image capture device comprising:

   an array of spaced apart radiation sensors for providing output signals that are a function of the incident radiation from an image onto each radiation sensor;
   array electronics dispersed in the spaces between the spaced apart radiation sensors for receiving the provided output signals so as amplify the provided output signals to facilitate image capture; and
   a lens array positioned so as to focus the radiation of an image to be captured onto said radiation sensors.

2. A compact image capture device according to Claim 1 and further comprising:

   a mechanical shutter positioned proximate said lens array for controlling which images are radiated onto said array of radiation sensors.

3. A compact image capture device according to Claim 1 wherein said array electronics is comprised in part of a plurality of current multipliers, corresponding in number to the number of radiation sensors, each connected to an associated radiation sensor.

4. An image capturing device comprising:

   an array of spaced apart groups of radiation sensors for providing output signals that are a function of the frequencies of incident radiation from an image onto each radiation sensor;
   array electronics dispersed in the spaces between the spaced apart groups of radiation sensors for receiving and amplifying their provided output signals to facilitate image capture; and
   a lens array positioned so as to focus the frequencies of radiation from an image to be captured onto associated ones of the radiation sensors in each of the groups of said radiation sensors such that each radiation sensor in a group provides an output signal that is a function of its sensed frequency.

5. A photosensor array of current generating photodetectors each in combination with an associated multiplying current mirror located adjacent thereto and comprised of one input transistor and at least two output transistors where the generated photocurrent from each photodetector is multiplied by an integer equal to the number of output transistors in the associated multiplying current mirror and to provide the multiplied current as an output signal.

6. The photosensor array according to Claim 5 and further comprising:

   correlated double sampling circuits connected to receive the output signal of an associated multiplying current mirror for providing an output that minimizes the dark current and noise from the current generating photodetectors.

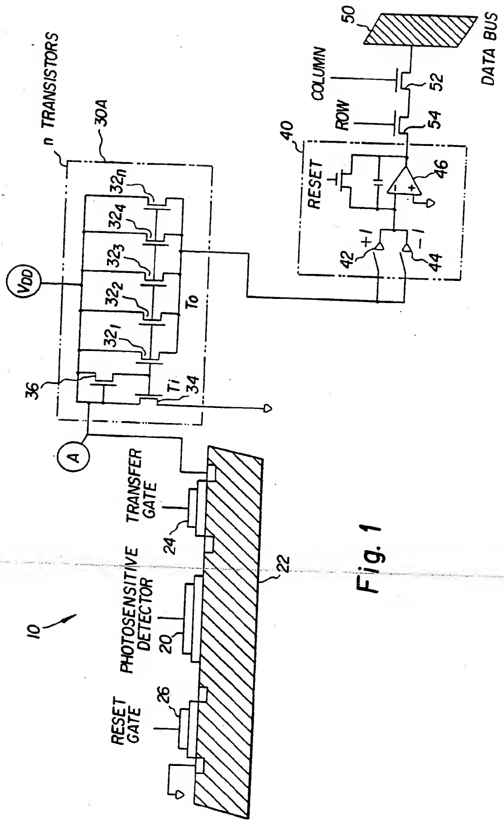
7. The photosensor array according to Claim 6 and further comprising:

   row and column select means for connecting the output from the correlated double sampling circuits to a data bus.

8. The photosensor array according to Claim 6 in combination with a camera wherein said photosensor array is exposed to the image to be captured by said camera so as to provide multiplied correlated double sampled current signals that represent said image to the data bus.

9. The photosensor array according to Claim 5 and further comprising, a lenslet array having a number of lenslets corresponding in number to the number of current generating photodetectors each lenslet positioned so as to focus incident radiation onto an associated current generating photodetector, each lenslet being a refractive/diffractive lenslet wherein the center of the mechanical optical axis of each lenslet is displaced relative to the displacement of its associated photosensor's radial distance from the optical axis of the lenslet located in the center of the array.

10. A photosensor array of current generating photodetectors each in combination with an associated multiplying current mirror located adjacent thereto and comprised of one input transistor and at least one output transistor having an emitter area which is equal to an integer multiple of the input transistor emitter area where the generated photocurrent from each photodetector is multiplied by an integer equal to the ratio of the output divided by the input transistor emitter area so as to provide an integer multiplied current as an output signal.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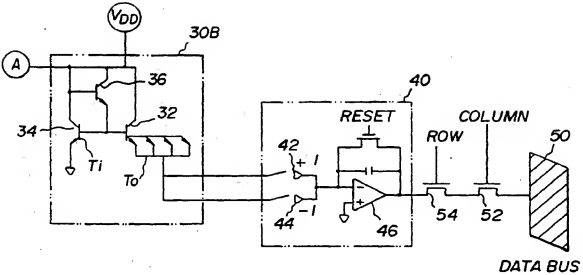
30A
V_{DD}
32_n
32_4
32_3
32_2
32_1
36
Ti
34
To
A
TRANSFER GATE
24
PHOTOSENSITIVE DETECTOR
20
22
RESET GATE
26
10
40
RESET
46
42
44
+I
-I
ROW
54
COLUMN
52
50
DATA BUS

Fig. 1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30B
A
36
32
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Ti
To
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RESET
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46
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52
DATA BUS

Fig.2

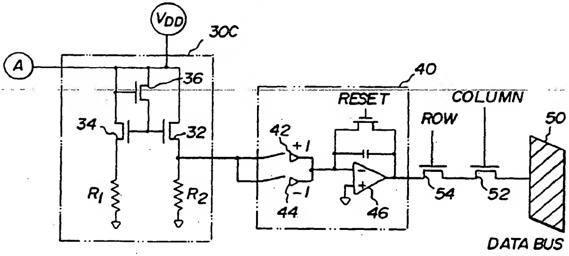
VDD
30C
A
36
40
RESET
COLUMN
ROW
50
34
32
42
+1
-1
R1
R2
44
46
54
52
DATA BUS

Fig. 3

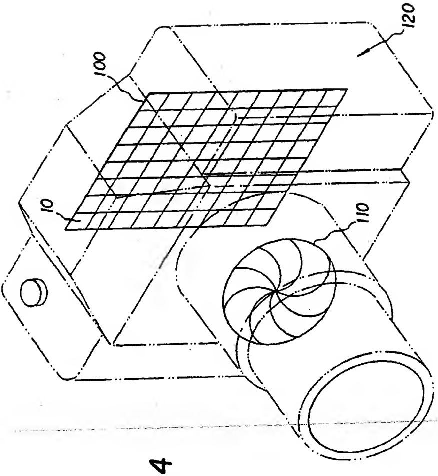

Fig. 4

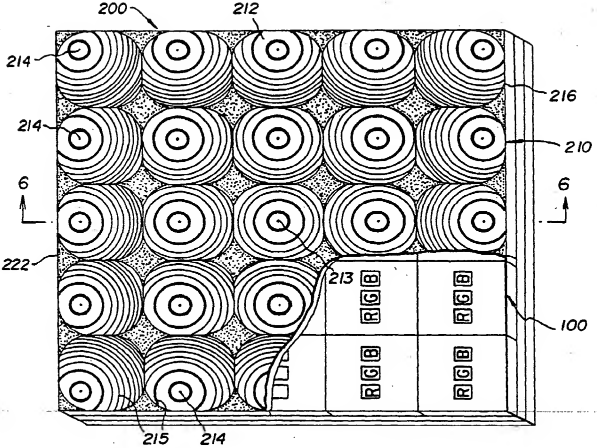

Fig. 5

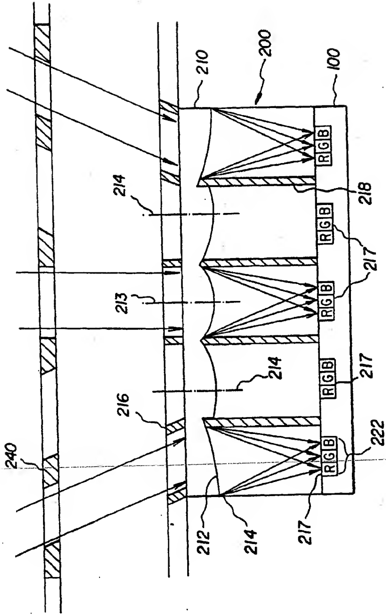

Fig. 6

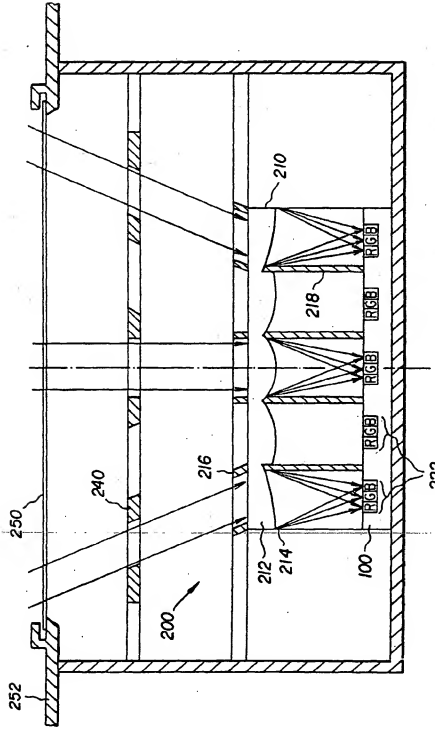

Fig. 7

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